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Study on Safety Assessment and Renovation Measures of a Reservoir Dam

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Abstract. According to the status quo of a reservoir dam, relevant hydraulic calculations and structural calculations are carried out on the dam body and its ancillary buildings, which reveal that the dam body was not up to standard for flood control, the left abutment of the dam body was leaking, sliding resistance of downstream slope of dam body was insufficient, the height of the spillway side wall was insufficient, and length of the stilling pool was insufficient and so on. In response to these problems, the corresponding engineering and technical renovation measures were proposed for the main buildings of the dam. The results of finite element analysis and the implementation of renovation measures show that the renovation plan is economically reasonable and technically feasible, the reservoir diseases problems can be eliminated, the reservoir functions can be restored, and the renovation effect is obvious.

Earth rock dams occupy a considerable proportion in the early construction of small reservoir dams in our country. Problems have appeared in some of them, such as dam body leakage, dam slope instability, failure of drainage measures, failure of flood control standards and so on after operating for many years, under the combined action of one or more factors such as unreasonable original design, low-level construction quality, unfulfillment of later operation management, untimely maintenance, earthquake disasters, termite disasters and so on [1]. The diseased reservoirs, which are out of repair for a long time, not only have low economic benefits, but also have great potential safety hazards, which seriously restrict the development of the comprehensive benefits of the reservoirs[2]. Therefore, it is imperative to improve and renovate the diseased reservoirs and restore the comprehensive performance of the old reservoirs. Taking a homogeneous earth reservoir dam as a typical case, this paper reveals many kinds of diseases existing in the homogeneous earth dam by calculation and analysis, and puts forward corresponding renovation measures, which can provide ideas and technical references for the renovation scheme of similar reservoir dams[3].

General Situation of Engineering

A reservoir is located in a ditch in the upper reaches of Xian River, a tributary of Long River. The dam site is located in Changsha Bayi Village, Dining County, 8 km away from the county. There is no flood control and rescue road directly to the dam top, and traffic here is inconvenient. The total reservoir capacity is 129,000 m^3, the dead reservoir capacity is 96,000 m^3, the designed irrigation area is 312 mu, and the actual irrigation area is 100 mu. It is a small (2) type water conservancy project that is mainly based on irrigation and has comprehensive utilization of flood control. The reservoir dam is a homogeneous earth dam. It is with a maximum height of 11.21m, a bottom elevation of 463.06m, a top elevation of 474.27m, a top width of 2.7m, a top length of 89.60m and a bottom maximum width of 44.30m. The upstream slope ratios are 1:1.6 and 1:1.94 from top to bottom, and the downstream slope ratio is 1:1.8. The upstream slope of the dam is protected by 100 mm thick C15 concrete with 50

mm thick crushed stone level under. The top of the dam is protected by 100 mm concrete with 50 mm thick crushed stone level under. The downstream slope of the dam is not protected.

The reservoir was strengthened in 2009, but the renovation is not complete. There are still serious diseases in the reservoir project, which endanger the safety of the dam. After approval by the Water Administration, it is confirmed that the reservoir dam safety category is three types of dams. In order to ensure the safety of the building itself, it is necessary to renovate it in time, therefore, the reinforcement of a reservoir is very necessary and should be implemented as soon as possible.

Reservoir Safety Assessment and Result Analysis

Reservoir Flood Control Capacity Analysis

(1) Verification of dam crest elevation

According to the data's of a reservoir, such as annual average maximum wind speed V=10m/s, dam blowing distance D=120m, upstream slope ratio m=1.6, 1.94, and average water depth H in front of the dam, the super elevation of the dam top is calculated according to the norms. In unusual operation cases, calculation is based on the annual average maximum wind speed, and in normal operation cases, calculation is based on 1.5 times of the annual average maximum wind speed. The calculated crest elevation of a reservoir dam is 474.37m, and the current crest elevation is 474.27m. The current crest elevation of a reservoir dam does not meet the 20-year once-in-a-flood design, so the crest of a reservoir dam cannot meet the requirements of the national standard for flood control.

(2) Verification of dam crest elevation Analysis of Flood Resistance Capacity

According to the results of reservoir flood regulation, safety review and engineering quality evaluation of safe super elevation of the dam and flood discharge from flood discharge buildings, the current flood resistance capacity of reservoir dam cannot reach the design standard of once in 20 years under normal operation . Therefore, the current flood resistance capacity of reservoir dams does not meet the requirements of the norms.

(3) Safety Analysis of Flood Discharge Buildings

At present, the structure of reservoir spillway is in good condition, and its operation is normal. Discharge capacity calculation of spillway, hydraulic calculation of chute and energy dissipation calculation of stilling basin are carried out for spillway structures. According to the results of hydraulic calculation of spillway chute, the exceeding height of side wall of spillway chute in the first section of spillway does not meet the requirements of norms. According to the hydraulic calculation results of stilling basin, the length of stilling basin of spillway does not meet the requirements of norms. Therefore, the safe discharge of reservoir design flood cannot be guaranteed.

Dam Seepage Stability Analysis

Based on the analogy of similar projects nearby, the physical and mechanical indexes of dam soil required for seepage and stability of dam body are proposed, and the geological parameters of dam filling and rock (body) of dam foundation are put forward. According to Darcy's law, seepage stability analysis is carried out. Seepage calculation considers plane steady seepage and isotropy of soil layer, the same as the actual seepage movement is simplified to two-dimensional problem [4].AUTOBANK analysis software is used for seepage analysis, and finite element method is used for seepage calculation under several calculation conditions. The calculation results show that the average hydraulic gradient of the dam is less than the critical gradient, and the dam will not be damaged by flowing soil and piping.

A seepage point is observed at 468.5m height of the left abutment of the dam. The flow rate is 3L/min measured by the triangular weir. According to the actual site inspection, the water level of the reservoir was 469.85m at that time. It is analyzed that the seepage originated from the reservoir area, and the seepage flow from the mudstone fissures. According to the analysis, the seepage originates from the reservoir area and there is leakage around the left abutment of the dam.

Anti-sliding Stability Analysis of Dam Body

The Swedish arc method of the effective stress method is used to calculate the stability of dam slope. According to norms, the slope stability analysis under multi-working conditions should be carried out in this project. The calculation program adopts AUTOBANK to carry out finite element analysis.

The maximum cross-section of the dam is selected as the calculation section. The calculation conditions: normal operation conditions: normal water level, design flood level, dead water level and one third of the upstream slope water level. The results of minimum safety factor of anti-sliding stability of upstream and downstream slopes under various working conditions are shown in Table 1.

Table 1. Table of safety coefficient for minimum anti-sliding stability of upper and lower dam slopes

Calculation Condition		Upstream Dam Slope	Downstream Dam Slope	Standard Value
Normal Operation	Normal Water Level	*1.748*(Conformity)	*1.068*(Inconformity)	*1.15*
	Design Flood Level	*1.785*(Conformity)	*1.052*(Inconformity)	*1.15*
	Dead Water Level	*1.193*(Conformity)	*1.153*(Inconformity)	*1.15*
	Upper Third Of Dam Slope Water Level	*1.45*(Conformity)	*1.131*(Inconformity)	*1.15*
Abnormal Operation	Checking Flood Level	*1.846*(Conformity)	*1.044*(Inconformity)	*1.05*
	Suddenly Dropped to Dead Water Level	*1.208*(Conformity)	*1.145*(Inconformity)	*1.05*

It can be seen that the anti-sliding stability of the upstream slope meets the requirements of norms under normal and abnormal operation conditions, while the downstream slope meets the requirements of norms at the dead water level and one third of the upstream slope water level. However, the anti-sliding stability of the downstream slope under the design flood level, check flood level and normal water level do not meet the requirements of norms.

Renovation of Reservoir Dam Project

Renovation Measures of Flood Control Buildings

In order to meet the requirements of flood control, the upstream side of the dam top is equipped with L-shaped C20 reinforced concrete wave wall, which is 1.60 m high, 1.0 m wide at the bottom, 0.3 m wide at the top. The wall top elevation is 475.47m [5]. This design demolishes the existing spillway stilling bucket, which uses M7.5 masonry stone. The length of stilling pool is increased from 2.0m to 3.1m. The floor is placed on mudstone foundation, which uses C20 concrete. The side wall uses M7.5 masonry stone, which is 1.2m high. The stilling bucket is set at the end, which is 0.5m high.

Anti-seepage Design of Left Abutment of Dam

Generally, curtain grouting is often used for seepage control in dam abutment design [6]. In this design, the curtain grouting treatment is carried out for the cross section of 0-12.00-0+018.00 dam body around the outlet point. The single rows of holes with a distance of 2.0m are adopted. The holes are divided into three sequential holes, dandified in sequence and grouted from bottom to top. A total of 21 holes are arranged. The drilling footage is 267m. The curtain grouting is 210m. The grouting lower limit is controlled by 10m below the normal water level.

Design of Downstream Slope Regulation

The downstream dam slope stability does not meet the requirements of norms at conditions of design flood level, check flood level and sudden drop. Therefore, the downstream slope is treated with thick shaping and slope protection [7]. The downstream slope is equipped with a 2.0m wide horseway at 465.29m, longitudinal and transverse drainage ditches on the inside or both sides of the horseway. The slope ratios from the upper side of the horseway to the top of the dam are 1:2.0, and the slope is protected by C15 concrete lattice structure and grass slope protection. The slope ratios from the lower side of the horseway to the foot of the dam are 1:1.0, and the body under the horseway is slope drainage body[8].

Contrastive Analysis of Dam Stability Calculation before and after Renovation

Under normal operation conditions, the calculation conditions after renovation: the stability of downstream slope during the stable seepage period of the normal water level of 473.03m; the stability of downstream slope at the design flood level of 473.42 m; and the stability of downstream slope at the dead water level of 466.38m. The basic seismic intensity in the reservoir area is less than VI, so the influence of earthquake cannot be considered in the calculation of slope stability.

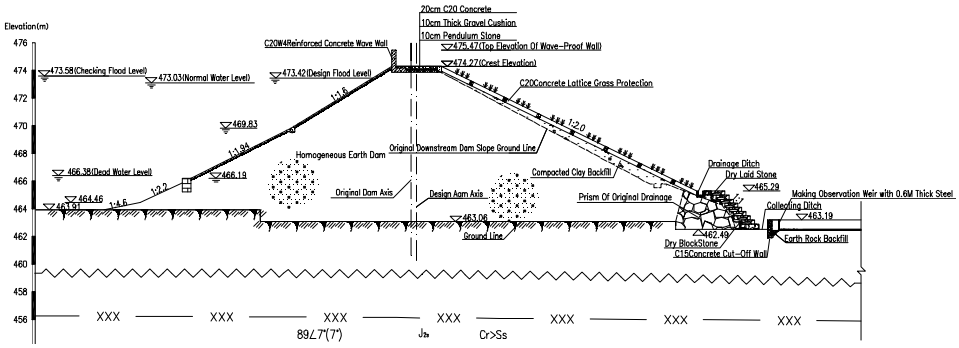

Figure 1. Cross-sectional drawing of downstream dam slope regulation

The Swedish arc method in the effective stress method is used to calculate the stability of dam slope, and AUTOBANK is used for finite element analysis and calculation. The results are compared with those before renovation. Result comparison statistics are shown in Table 2. The diagram of dangerous sliding surfaces of downstream dam slope under various working conditions is shown in figure 2, figure3 and figure 4.

Table 2. Comparison table of safety factors of down-stream dam slope stability before and after renovation

Calculation Condition	Anti-sliding Stability Coefficient Calculated Value (Before Renovation)	Anti-sliding Stability Coefficient Calculated Value (After Renovation)	Standard Value
Downstream Dam Slope Under Normal Water	*1.068*	*1.165*	*1.15*
Downstream Dam Slope Under Design Flood	*1.052*	*1.159*	*1.15*
Downstream Dam Slope Under Checking Flood	*1.044*	*1.096*	*1.05*

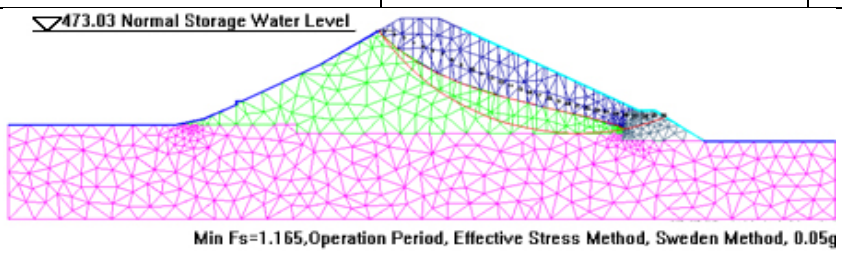

Figure 2. Schematic diagram of downstream dam slope stability under normal storage water level

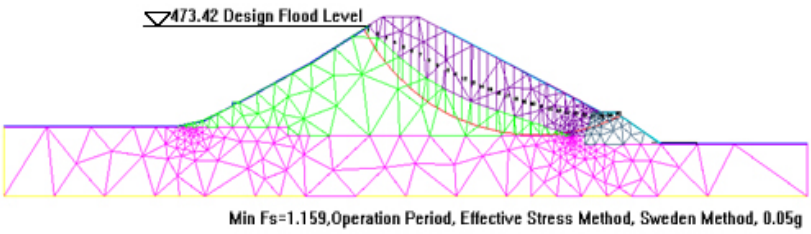

Figure 3. Schematic diagram of downstream dam slope stability under design flood level

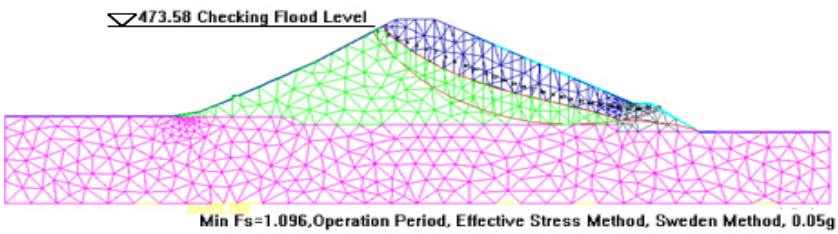

Figure 4. Schematic diagram of downstream dam slope stability under checking flood level

The table of stability safety factors of downstream dam slope before and after renovation and the schematic diagram of dam slope stability calculation show that the anti-sliding safety factors of downstream dam slope after renovation are greatly improved compared with those before renovation. The stability safety factors are larger than the safety value of norms. The downstream dam slope tends to be stable and the renovation measures are effective.

Conclusion

(1)Generally, for small reservoirs, the typical renovation works of earth-rock dam diseases include the renovation of flood control structures, seepage control of left abutment, slope strengthening and protection, drainage prism shaping and so on.

(2)Through the calculation and analysis of finite element software under different conditions before and after reservoir renovation, it can be concluded that the engineering renovation measures are economically reasonable and technically feasible. After the implementation of the renovation measures, the disease problems can be eliminated, the reservoir functions can be restored, and the overall project image can be improved. The renovation effect is obvious.

(3)In this paper, the renovation of a typical earth-rock dam disease reservoir is carried out. The engineering measures and calculation methods can provide reference for similar projects and for engineering designers.

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